VERBAL AND VISUO-SPATIAL PROCESSING DEMANDS IN WRITING

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Writing research has recently begun to consider the role that limitations in cognitive capacity play in the writing process, thus obligating writing researchers to examine existing theories of cognitive limitations. This dissertation reviews four major classes of cognitive processing models that might serve as theoretical bases for extension to written language production. Four experiments assess the merits of a reconceptualization of Kellogg's (1996) model of working memory and writing by emphasizing the role of resource pools rather than binary functioning cognitive structures. Empirical findings support the recent trend toward multicomponent classes of working memory or resource models, particularly those that distinguish between visuo-spatial and verbal/phonological processing. Results also indicate that there is a significant visuo-spatial component in the planning stages of writing.

CHAPTER 1
INTRODUCTION

Writing research has recently begun to consider the role that limitations in cognitive capacity play in the writing process. A common assumption is that writers have a limited cognitive capacity, the size and/or efficiency of which varies between individuals. Research on cognitive capacity and writing is relatively new compared to studies of capacity limitations in reading, and to spoken language production and comprehension (see Gathercole and Baddeley, 1993 for an overview), obligating writing researchers to develop and refine appropriate models necessary for theoretical development and testing. Fortunately, the nature of human processing and storage limitations has long interested psychologists working within an information processing framework, and accounts of other language production tasks have led to the development of constructs such as working memory, resource capacity, and mental workload.

In part, the contribution of this dissertation lies in the extension of debates in the working memory and attention literature to the nearly untouched domain of writing. As both a thinking and language production task, writing research may challenge these existing models. Four approaches to cognitive limitations are introduced below, followed by a critical analysis of information processing theory development, and rationale for the formation of a hybrid model that the employs elements of these models with the greatest explanatory power for written language production tasks.

- Structural theories were popularized in the 1950s with experimental investigations of the dichotic listening task which revealed that attention was severely limited (Cherry, 1953; Broadbent, 1958; Moray, 1959). Several classes of theoretical models were generated to localize the point in information processing where the bottleneck occurs. Early-selection theories claimed that this bottleneck is in the early processes such as perception, and late-selection theories pointed to stages of decision making and response selection as the limiting stages of information processing.
- Early human factors research in the measurement of mental workload led to the conceptualization of the human operator possessing a pool of limited-capacity resources (Knowles, 1963). This resource capacity approach offers the simplest framework for interpreting the demands placed on the writer by postulating an undifferentiated pool of mental resources (Kahneman, 1973). Performance on any given task declines only when the aggregate of task demands exceed the capacity of resources.
- An alternate conception of this resource economy makes a distinction in the type of resources available at any given moment. This "multiple resource" approach posits that there may be various types of resources and that different tasks may require different types of resources in various compositions. The most widely supported division of resources is a neurologically plausible division between visuo-spatial and verbal resources (Wickens, 1984; Friedman & Polson, 1981). Friedman and Polson (1981) proposed a framework with the intention of extending multiple resource models to our understanding of cerebral specialization phenomena. They suggest that the physically distinct cerebral hemispheres can be seen as independent resource systems, and that

the left and right hemispheres together form a system of two mutually inaccessible and finite pools of resources.

- Baddeley & Hitch's (1974) model of working memory is a multi-component system for both the storage and the processing of verbal and visuo-spatial information. It has three primary components: a limited-capacity central executive and two peripheral slave systems. One of these slave systems, the phonological loop, handles verbal and auditory information while the other, the visuo-spatial scratchpad, is specialized for processing visual and spatial information.

Most approaches to cognitive processing limitations recognize a division in processing for verbal and visuo-spatial tasks, owing to the vast literature on hemispheric differences. Since the doctrine of cerebral localization in the late 1700's, particular cognitive functions have been assigned to specific regions of the brain. Generally, visuo-spatial processing has been localized to the right hemisphere while the left hemisphere is believed to play a stronger role in verbal tasks. Popular multiple resource models (Wickens, 1984; Friedman & Polson, 1981) and Baddeley and Hitch's (1974) working memory model build on this neurological separation of visuo-spatial and verbal processing.

As a writer plans ideas, translates ideas into prose, types or handwrites sentences, and monitors all of these activities, many demands are placed on temporary storage and processing capacity. This dissertation seeks to provide an account of the division of labor between visuo-spatial and verbal processing demands and capacity limitations as they influence the writing process. Special treatment will be given to the wholly untouched question of how visuo-spatial resources constrain writing. The balance of this chapter

critically reviews the literature regarding the models introduced above, focusing on their assumptions about the nature of human cognitive limitations. The review concludes with a summary and critique of existing literature, followed by a proposal for an adapted theory of working memory which is tested in Experiment 1. Experiments 2a and 2b compare the involvement of phonological and visuo-spatial processing in essay writing, and Experiment 3 investigates the role that writing topic plays in the resource demands of writing.

Resources and Structures

Two hypothetical constructs have greatly influenced theory development addressing cognitive limitations. First, we will consider the notion of *limited processing resources* that are demanded by non-automatic tasks. According to resource theories, performance declines only when the aggregate of task demands exceed the available resources. For example, when someone uses a word processor to translate an idea into text, we might expect that simultaneously generating new ideas and editing grammatical and spelling mistakes would cause a disruption in the rate at which text is generated. Juggling that writing task with talking on the telephone or listening to the radio would further drive down performance. A second construct proposed to explain processing efficiency is referred to as *structure*. According to a structural view (Pashler &Johnston, 1989), when people attempt to simultaneously engage in competing mental operations, incompatible stages or processes are initiated, which results in interference between tasks. In other words, two tasks compete when they each simultaneously require a single common process. For example, we would expect interference between two tasks such as conversing on the telephone while simultaneously listening to a radio interview, more so than the dual-task combination than carrying on a conversation while riding a bike,

presumably because similar processes are demanded by producing and comprehending audible speech.

Two classes of theoretical models of attention have emerged from consideration of these hypothetical variables. These are *capacity* or *resource theories*, described by Kahneman (1973), and *structural theories* which began with Broadbent (1958) and recently have been elaborated by Pashler and his associates (Pashler & Johnston, 1989; Pashler & Carrier, 1995). After considering structural and capacity theories in more detail, we will examine multiple resource models and Baddeley's working memory model as each offer a rapprochement of structural and capacity theories. Further, Experiment 1 will reveal empirical findings suggesting that writing research may be best guided by a model that combines the strengths of both working memory and multiple resource theories.

Capacity Theories

How is it that we may become less conscious–rather than become entirely unaware – of some things when we become more conscious of others? Capacity theories seek to explain this common experience by suggesting that some resource pool is approaching its limitation. Thus, when a primary task demands more of these resources, fewer are available for a concurrent secondary task. Whereas structural theories assume that structures are dedicated to one task at a time, the resource view assumes that capacity can be allocated between separate activities in graded quantity.

Nearly all of the original paradigms investigating the nature of resources (or mental capacity or effort) involve presenting two tasks to an individual to process simultaneously, or so-called dual-task conditions. Resource theories in large part were created to explain

instances where two processes were simultaneously activated. Perhaps the earliest task (although not a traditional dual-task) was the Stroop task where reading processes were observed to compete with color naming processes for a common pathway. Although theorizing about pathways has evolved into structural theories of attention, the basic question about mechanisms of interference is the same. In the 1950s British psychologists Broadbent, Moray, and others began working with the dichotic listening task, to test various structural models of the selection of attention; for example, late versus early selection. The probe technique emerged shortly thereafter, where participants respond to a discrete stimulus while performing some primary task. A participant's baseline reaction time was subtracted from his or her reaction time to a tone presented during performance of a primary task in order to compute an interference reaction time, which was assumed to be an index of mental effort.

Kahneman (1973) brought unity to the concept of capacity as an intervening variable in dual-task performance. His ideas and synthesis of the research at that time facilitated the evolution of the resource metaphor from an intuition to a quantitative theory with testable predictions. Since the early 1970s, capacity theories have continued to influence basic and applied research. Capacity theories are especially important in applied research, where workload measurement is investigated. Capacity theories have been applied to aircraft cockpit design (Rolfe, 1971), the failure detection of autopilot systems (Wickens & Kessel, 1980), target tracking systems used by military pilots (Fracker & Wickens, 1989), and in the design of visual displays requiring the integration of information from several sources (Yee, Hunt, & Pellegrino, 1991; Boles & Wickens, 1987). The notion of resources has also played a role in the more basic pursuits of

learning, memory, and writing research. Researchers studying automaticity have also benefited from the resource conceptualization of attention. As a task becomes more automatic, fewer resources are needed for its successful completion (Laberge, 1973).

Despite the explanatory power over dual-task performance and success in applied settings, capacity theories have received some criticism. Navon (1984) argued that most effects interpreted in terms of resources can also be accommodated well by theories that do not assume any limit on resources and by theories in which the resources construct does not exist at all. Navon describes a diverse range of phenomenon that are typically discussed in terms of resources, and takes issue with how necessary resource terminology is for dealing with these phenomena. Manipulations of *motivation level* through payoff schemes may be interpreted in the resource framework as regulating the amount of resources allocated to the task. Navon argues that resources are not necessary to explain the effect of motivation though, and he suggests that processing may be modulated without any change in the supply of resources. In manipulations of *task difficulty*, the more difficult a task, the more resources are said to be needed by that task. Navon suggests that other factors such as poor luminance contrast might impair the quality of sensory data available to a process independently of resources. Manipulations of *task complexity* are typically explained by the notion that more complex tasks require more resources. Navon argues that independent of resources, more complex tasks may require more steps or mental operations, thus presenting more opportunity for errors. *Dual-task deficits* are typically thought to degrade the performance of the primary task by curtailing the amount of resources in its service. Navon points to other possible sources of interference such as structural interference, some form of cross talk similar to that in

parallel phone lines, or interfering patterns of activation in which inhibition necessary for one task disrupts activation on concurrent task.

In defense of resource theories, some researchers (Herdman & Friedman, 1985; Wickens, 1976) claim that distinguishing between resource and structure theories may be accomplished by manipulation of task priority in dual-task conditions. If performance can be traded off from primary to secondary tasks and vice versa, then their interpretation is that the two tasks interfere because the are consuming common resources. If the two tasks compete for a common structure then the expectation is that performance will not trade off between the two tasks in a gradual manner. Navon (1984) counters by arguing that even single structural mechanisms could be timeshared between tasks by some schedule of queuing or alternation.

Despite continuing debate, the resources construct continues to influence information processing theory development and human factors concerns, and is at the very least a useful metaphor. It seems likely that resource theories will continue to flourish as long as continue to be useful in applied psychology.

Structural Theories

Early studies of the limitations of attention often involved the dichotic presentation of verbal material. Subjects typically wore stereo headphones, and different messages were simultaneously presented to each ear. Participants attended to one of the two messages and repeated it aloud immediately after hearing it (shadowing). This technique ensured that the participants focused on one of the two messages. Experimental investigations of the dichotic listening task revealed that attention was severely limited (Cherry, 1953; Broadbent, 1958; Moray, 1959). Several classes of theoretical models were generated to

localize the point in information processing where the bottleneck occurred. Early-selection theories claimed that the bottleneck was in the early processes such as perception, and late-selection theories pointed to stages of decision making and response selection as the limiting stages of information processing.

Another paradigm was also often used in the investigation of the limitations of attention. The psychological refractory period (PRP) paradigm (Bertelson, 1967; Welford, 1967), also known as the overlapping tasks paradigm (Pashler, 1984), involves the presentation of two stimuli (S1 and S2) in rapid succession. Participants make a response to each stimulus (R1 and R2) as quickly as possible. Using this paradigm, many researchers (Kantowitz, 1974; Pashler, 1984; Pashler & Johnston, 1989; Fagot & Pashler, 1992) concluded, as did the late-selection theorists, that limitations in processing were localized in the response initiation phase.

A subsequent extension of this structural model by the late-selection theorists postulated that there is not a single stage or mental operation that acts as the source of interference. Instead, a limited-capacity central processor, when engaged by one task, is unavailable to a second task requiring the same operation. Thus, the performance of the second task will necessarily deteriorate. By suggesting that there are a number of operations that require the exclusive attention of the limited-capacity central processor in order to proceed, this view permits more than one bottleneck in the information processing system. Restrictions in the ability to carry on multiple mental computations may occur at a variety of stages, including perceptual identification, decision and response selection, response initiation and execution (Pashler & Johnston, 1989), and motor mechanisms (Kahneman, 1973).

Broadbent (1982) criticized studies of continuous performance that rely on accuracy measures because they cannot discriminate between the predictions of capacity theory regarding simultaneous mental processing of both tasks and the predictions of structural models regarding strategy switching. Pashler and Johnston (1989) incorporated Broadbent's suggestions when they investigated dual-task interference with the PRP. They argued that this paradigm potentially provides much more detailed information about the time course of dual-task interference than is obtained in continuous dual-task studies.

Pashler and Johnston divided models of dual-task interference into two categories: 1. capacity sharing models discussed earlier, and 2. "postponement models" which are structural in nature. In postponement models, some bottleneck stage or process cannot operate simultaneously for each of two overlapping tasks. As a result, processing of this stage in the second task is literally postponed. This produces the relatively straightforward hypothesis that as stimulus onset asynchrony (SOA) between S1 and S2 is reduced, there should come a point at which any further reduction in the SOA produces a corresponding increase in the duration of R2. However, even when this prediction is confirmed, it does not seem to contradict predictions from the capacity theory.

Kahneman (1973) addressed the notion that structural theories and a limited capacity theory may account for the same findings. He observed that the assumptions of structural theories are more restricting than the limited capacity models, and that predictions, especially for the PRP, have typically failed to be confirmed. Pashler and Johnston concede that the PRP paradigm has been studied somewhat less of late perhaps reflecting Kahneman's early concerns.

A major finding that has frequently been observed with the overlapping tasks paradigm is a slowing of the R1relative to single-task performance (Kahneman, 1973). Similar findings in discrete movement research are thought to indicate the increased effort needed to compile a more complex movement (Henry & Rogers, 1960). R2 slowing is readily accounted for with the capacity models because both tasks are assumed to be performed with depleted allocations of capacity. Postponement models, in contrast, do not predict this slowing directly. It has been suggested that R1 slowing may result from a grouping strategy in which the subject essentially treats S1 and S2 as a compound stimulus and selects a corresponding compound response (Pashler & Johnston, 1989). Other strategies have been proposed as well, but in any case, R1 slowing by itself is not thought to be especially diagnostic of the underlying causes of dual-task interference.

Because both capacity and structural models can provide a plausible account of the basic results, more analytic tests that make distinctive, non-obvious predictions are necessary. Pashler (1984) used a chronometric approach to develop a method for testing postponement models inspired by additive factors logic (Sternberg, 1969). By manipulating task factors that increased or decreased the duration of selected stages of processing and looking for effects that were additive (or underadditive), Pashler was able to test hypotheses about the locus of the singe-channel bottleneck. Pashler reported a preliminary study using this methodology that found underadditive effects that were consistent with the predictions from a postponement model, and could not be explained with capacity theory. This study supported the late-selection class of theories, suggesting that a bottleneck exists either in the decision or response selection stages or in both stages.

Postponement models predict that effects at stages prior to the bottleneck should become progressively smaller at shorter SOAs. As SOA shortens, the wait for the processor is thought to become progressively longer, and the proportion of trials on which delay in early stimulus processing of S2 will have any effect on RT2 progressively decreases. Although Pashler (1984) only used one SOA and could not test this prediction, Pashler and Johnston's findings (1989) lend stronger support to the postponement model with a bottleneck at the stages of decision making and/or response selection. In particular, results indicating underadditivity present a problem for capacity theory as capacity models predict that dual-task slowing of RT2 should interact overadditively with factors that increase the difficulty of the second task.

There seems to be a general acknowledgement in the dual-task literature that structural theories have very little empirical support outside of isolated laboratory tasks. Structural theories have played a large role in studies of cognitive limitations, particularly in their focus on mental stages. It is interesting in a historical sense that structural assumptions have been carried over into the Baddeley and Hitch (1974) model of working memory that will be discussed in detail later. Baddeley and Hitch, after all, were trained in Broadbent's lab where much of the early structural theorizing and testing took place.

Multiple Resource Theories

A search for a compromise to the structure/capacity debate has led directly to multiple resource models (Navon & Gopher, 1979) where resources are declared to reside within structures or pools. Until multiple resource models emerged, interference was thought to depend exclusively on either the extent that two tasks draw on a common resource pool or structural limitations where some stage of processing cannot proceed in

parallel with another. Neither of these accounts explains all of the phenomena related to interference though. The central capacity notion cannot explain why some secondary tasks interfere more with one primary task than another equally difficult primary task. For example, vocal responses interfere more than spatial responses with recall of a sentence, but less than spatial responses with recall of a line diagram (Brooks, 1968). Pure structural models are also inadequate because processes that share similar stages or mechanisms may interfere with each other, but they seldom block each other completely (Navon & Gopher, 1979). For example, when Triesman and Davies (1973) presented participants with stimuli simultaneously to the same modality, performance was impaired, but not entirely impeded.

Multiple resource theory posits that there may be various types of resources and different tasks may require different types of resources in various compositions resources (Norman & Bobrow, 1975; Navon & Gopher, 1979; Wickens, 1984). On the one hand this approach is structural in the sense that it identifies the source of interference as overlapping mechanisms. On the other hand, multiple resource theory is a capacity approach, because it does not assume that a mechanism can be accessed and used by only one process at a time. Rather, mechanisms have a capacity that can be shared by several processes until those processes demand more resources than the capacity allows. Thus, multiple resource theory is a marriage of capacity and structural models where structure is important, but each structure is limited by its own capacity.

Wickens (1984) proposed a multiple resource model that accounts for a great deal of the empirical findings from dual-task studies. This model assumes that the extent to which two tasks share common resource pools determines how much they will interfere in a dual-task paradigm. In particular, the resource architecture of Wickens's model contains

three dimensions derived from traditional psychological dichotomies: (a) Based on the general finding that it is easier to time-share an auditory and visual task than two auditory or two visual tasks, Wickens proposed a separation of resource pools specialized for dealing with different *processing modalities.* (b) The *processing codes* dimension distinguishes information that is spatial or analog from that which is verbal or linguistic. (c) Wickens proposed a separation of *processing stages* based on the finding that tasks demanding either response processes or cognitive/perceptual processes will interfere with each other to a greater extent than will a perceptual and a response task.

Friedman and Polson (1981) proposed a framework with the intention of extending the resource metaphor to our understanding of cerebral specialization phenomena. Essentially a special case of a multiple resources model of limited-capacity, they suggest that the physically distinct cerebral hemispheres can be seen as independent resource systems. Specifically, the left and right hemispheres together form a system of two mutually inaccessible and finite pools of resources. This conceptualization differs from other multiple resource models in that it is based, at least grossly, on the physical structure of the brain. In some respects this anatomical basis goes beyond the intent of earlier multiple resource theories, while at the same time taking a step back to the most clearly supported resource differentiation of all, the distinction of processing which is coded verbally from visuo-spatially coded processing. Ultimately however, their theory, like other multiple resource models, seeks to provide insight into the mechanisms that might be responsible for those patterns of task interference not easily explained by models postulating a single pool of undifferentiated resources.

Although the existence of multiple resource pools appeals to many researchers (Wickens, 1984; Friedman & Polson, 1981; Norman & Bobrow, 1975), others are skeptical (Navon, 1984). Navon and Gopher (1979) noted that multiple resource theory might leave researchers disconcerted by the prospect of devaluation of the precious time-honored concept of attention and that the proliferation of resources might seem strange or threatening. Those who favored the more conservative central capacity theory argued that multiple resource theory is not logically falsifiable and that it is impossible to know how many resource pools there are. Therefore, new resource pools could be postulated to account for any pattern of results. Multiple resource theory, as a class of models, may not need to be falsifiable to be worthwhile. Rather than struggling to find a critical test for the entire approach, researchers might do better by focusing on generating and testing specific multiple resource models that delineate the composition of resources.

Working Memory

Like the multiple resource approach, Baddeley and Hitch's (1974) model of working memory is another hybrid of structural and capacity models. Instead of resources within structures, this model implies both resource and structural components. The model's hybrid nature often goes overlooked, perhaps because working memory has been primarily connected with higher level language tasks such as speech production, vocabulary acquisition, and speech comprehension rather than the typical lower level cognitive studies of processing limits where the capacity/structure debate flourished. Working memory has recently become a popular construct in writing research because speech production, vocabulary acquisition and speech comprehension presumably share some characteristics with written language production.

The Baddeley and Hitch (1974) model evolved when neurological and experimental data did not fit assumptions concerning the functioning of the unitary short-term store in the modal model (Atkinson & Shiffren, 1968). In the modal model, the short-term store was positioned as the route information must take to gain access into a long-term store, but neurological evidence indicated that poor performance on an auditory memory span task was not linked to a long-term learning deficit (Shallice & Warrington, 1970). Nor did an impairment in the short-term store interfere with comprehension and production of speech (Vallar & Baddeley, 1984). Second, the short-term store was considered to play a major role in retrieval from the long-term store. However, a digit span task performed concurrently with the retrieval phase of a free recall task, did not depress accuracy of retrieval (Baddeley, et al., 1984a). Neither did rehearsal of a 6-digit number influence recall of paired associates (Baddeley, Thomson, & Buchanan, 1975). Third, a key postulate of the modal model was that the probability of information being transferred to long-term store was heightened by increased rehearsal. Yet, the time spent rehearsing target items interspersed at varying intervals in a longer list of words was unrelated to recall (Craik & Watkins, 1973). Nor did frequent rehearsal prior to the start of a free recall experiment improve recall of the rehearsed items (Tulving, 1966). Finally, another tenet of the modal model was the recency effect in free recall tasks was derived from information that remained in the short-term store. This was inconsistent with findings that the recency effect remained even when participants counted backwards by three's for 20 seconds after each word (Tzeng, 1973).

Baddeley's model is a multi-component system for both the storage and the processing of verbal and visuo-spatial tasks. It has three primary components: a limited-

capacity central executive and two peripheral slave systems. One of these slave systems handles verbal and auditory information (the phonological loop). The other is specialized for visual and spatial information (the visuo-spatial scratchpad) These slave systems do not represent pools of limited resources that can act in parallel like the central executive. Instead, they operate serially, in the same sense that a computer's printer may receive multiple print jobs, but can only perform one print job at a time.

The phonological loop is assumed to be most important in the production, comprehension, and development of language. Architecturally, it has two subcomponents: (a) a phonological store that is believed to hold phonological information for approximately 2 seconds and (b) an articulatory mechanism that is implicated in the transfer of written verbal material to the phonological loop. Because the working memory model emerged from research on verbal tasks, the phonological loop has received much more study than either the central executive or the visuo-spatial scratchpad. There are five empirical sources of support for the phonological loop. First, evidence for the articulatory control process comes from the word length effect: memory span is smaller for long words than that for short words (Baddeley, Thomson, & Buchanan, 1975). This is assumed to occur because rehearsal takes longer for longer words than for short words, allowing more decay to occur before the next rehearsal cycle. It is typically found that people remember as many words as they can read in 2 seconds (Baddeley, Thomson, & Buchanan, 1975). Second, performance is disrupted when participants vocalize some predefined pattern of speech (e.g., tee tah, tee tah) while they simultaneously perform some primary task. This articulatory suppression is claimed to engage the phonological store and block its ability to participate in accomplishing the primary task. Disruptions

have been observed in a variety of tasks, including vocabulary acquisition and serial learning (Baddeley, et al., 1984b). Third, performance degradation occurs when participants attempt to perform a primary task while irrelevant speech is presented that they are instructed to ignore. This procedure has been shown to disrupt serial recall of visually presented lists (Salame' & Baddeley, 1982). Fourth, acoustic or phonological similarity effects are common where the dissimilar sounding items are recalled better than similar sounding items is interpreted as evidence that the phonological store is speech-based (Conrad & Hull, 1964; Baddeley, 1966). Words or nonwords that sound alike interfere with each other in memory span tests more than semantically-related words that differ in their acoustic properties. Fifth, neuropsychological patients frequently have specific phonological loop deficits, but suffer no general cognitive impairment (Baddeley, Papagno, & Vallar, 1988).

The visuo-spatial scratchpad has been less researched than the phonological loop, but the notion that spatial and verbal processes may each draw on functionally separate resources is well supported (Wickens, 1984). Where phonological similarity effects have been observed in tasks believed to require the phonological loop, visual similarity effects have been observed in visuo-spatial tasks. It is common for stimuli that look alike to interfere with each other. Hue and Ericsson (1988) observed this phenomenon with Chinese characters in a study using participants who presumably had no experience with the Chinese language. Frick (1988) elaborated on the visual similarity effect, arguing on the basis of the frequency of errors like "P" being mistaken for "R" that images in visuo-spatial working memory are unparsed. Further evidence for the existence of a separate visuo-spatial and verbal storage systems comes from neuropsychological studies where

patients with right posterior lesions can be markedly impaired on tests of memory span for movements to different spatial locations, despite having normal auditory-verbal memory spans (De Renzi & Nichelli, 1975).

A separate visuo-spatial processing system is also claimed to be involved in planning and executing spatial tasks. For example, Japanese abacus experts can perform complex calculations without the aid of the abacus, and appear to do so by simulating the apparatus using visuo-spatial working memory (Hatano & Osawa, 1983). Researchers have also implicated the visuo-spatial scratchpad in keeping track of changes in the visual perceptual world over time (Kahneman, Triesman, & Gibbs, 1992), maintaining orientation in space and directing spatial movement (Thomson, 1983), and comprehending certain types of verbal information (Manin & Johnson-Laird, 1982).

The central executive component of Baddeley's model is described as a limited-capacity mechanism responsible for coordinating tasks and managing the two slave systems. It operates in a fundamentally different way than the two slave systems, because it may be actively involved in meeting the demands of two or more concurrent tasks. Accordingly, performance declines only when the collective task demands exceed the capacity of resources.

Baddeley acknowledges (1992) that embarrassingly little direct research has focused on the central executive and that it is somewhat of a catch-all component responsible for a wide range of attentional duties. Nevertheless, one source of evidence derives from the study of Alzheimer's disease, a disorder typically associated with deficits in tasks believed to depend primarily on central executive functioning. In one study (Baddeley, 1993), Alzheimer's patients were trained to do a visual task and a verbal task.

They then performed both tasks together in a dual-task paradigm. As the disease progressed, single-task performance remained unchanged, but dual-task performance dropped markedly. This effect was interpreted as support for the modularity of the central executive, reasoning that time-sharing ability is accomplished entirely by the central executive.

The Baddeley model has competitors other than single and multiple resource models (Kellogg, 1996). Martin, Shelton, and Yaffee (1994) postulate that verbal working memory may be further partitioned into subsystems for phonological and semantic representations. Hirst and Kalmar (1987) indicate that working memory might also be characterized to explain interference as a function of the semantic similarity of processing. Klapp and Netick (1988) suggest that working memory resources may be further divided between processing and storage. Ericsson and Kintsch (1995) challenge the utility of postulating resource limits and raise the point that experts in a domain circumvent short-term capacity limitations through the structures of long-term working memory.

Working Memory in Writing

Kellogg (1996) proposed a model of writing that details how specific writing processes rely on the main components of Baddeley's working memory model. In this proposal, Kellogg distinguishes among three language production processes: formulating, executing, and monitoring. Each of these involves two basic level processes. Formulation consists of planning ideas and translating them into sentences that may later be handwritten or typed. Execution includes programming (controlling motor movements) and executing (typing, handwriting, or dictation). Monitoring includes reading and editing. The model is very clear that writers do not necessarily progress serially from

formulating text to executing it, and then to monitoring what they have written. Instead, the model supports simultaneous activation of each of these processes, provided that the demands placed on the central executive do not exceed its capacity limitations. Thus, the model anticipates that the typing of a word or phrase may take place simultaneously with the formulation of new material or reading previously written material. This is possible only when execution is well-practiced and can proceed virtually automatically, so that central executive resources are not needed. In contrast, the basic processes of formulation and monitoring are much less likely to ever become automated.

Kellogg considers the demands that the basic processes of writing make on working memory. He hypothesizes that formulation places the heaviest burden on working memory, particularly on the central executive, but also on both slave components. Planning demands the resources of the visuo-spatial scratchpad particularly when writers plan by visualizing ideas, organizational schemes, supporting graphics, appearances of the orthography and layout. Creating ideas (Shepard, 1978) and recalling them from long-term memory (Paivio, 1986) can invoke visual imagery. Gathercole and Baddeley (1993) claim that planning also requires central executive resources in all its facets such as generating ideas, trying out various organization schemes, or debating the appropriate tone for a given audience. When formulating, writers covertly talk to themselves in the form of inner speech or pre-text as they are generating sentences (Baddeley & Lewis, 1981), thus activating the phonological loop. In particular, phonological representations of the words and sentences are stored in the phonological loop. To connect the phonological loop with formulation tasks Kellogg notes cases of apraxic and dyspraxic patients who make phonemic and other linguistic mistakes in speech and who also are impaired in

memory span tests and fail to show phonological similarity and word length effects (Waters, Rochon, & Caplan, 1992). Translating, unlike conversational speech production (Bock, 1982), demands central executive resources when the writer struggles to find just the right words and sentence structures. Long pauses and high degrees of expended cognitive effort suggest the involvement of the central executive in these cases (Kellogg, 1996) as well as the positive correlation of memory span with the ability to select lexical items for use in a sentence (Daneman & Greene, 1986). Kellogg adds that the involvement of the central executive in translation may vary with the demands of the task at hand. A writer composing polished final draft prose on the first attempt may require central executive resources to a greater extent than a writer composing a more conversational email to a friend.

Typing and handwriting (execution) are believed to make minimal demands on the central executive when highly practiced. In young children however, Bourdin & Fayol (1994) found that handwriting demands more capacity than speaking, consistent with the notion that novel activities of all kinds require the central executive to control the schemas used in motor output (Kellogg, 1996).

Gathercole and Baddeley (1993) claim that reading, one of the basic processes of monitoring, requires the resources of both the phonological loop and the central executive. Kellogg suggests that the most significant demand of monitoring stems from editing, not reading, because editing takes so many forms, ranging from the detection of a motor programming effort to a revision in the organization of ideas in a text (Kellogg, 1996).

Relevant Working Memory and Writing Research

Owing in part to its newness, little research has been reported that explicitly tests the implications of Kellogg's model. One prediction of the Kellogg model suggests that the phonological loop plays a strong role in monitoring. Jones, Miles, and Page (1990) introduced an irrelevant speech manipulation to explore phonological loop involvement in proofreading. Although proofreading is clearly not the same as editing one's own writing, it does involve some aspects of the monitoring process as described by Kellogg (1996). Jones, et al. compared participants' ability to detect two types of errors, contextual (grammatical and word choice) and non-contextual (spelling and typographical errors), while they heard either meaningful or reversed speech. The irrelevant speech consisted of a taped lecture either played forward (meaningful speech) or backward (reversed speech). The detection rate for non-contextual errors was disrupted in the meaningful speech condition, but this effect did not extend to contextual errors. No effects were observed for the reversed irrelevant speech manipulation, nor were there differences between reversed irrelevant speech and silence in a second experiment, lending support to the idea that a semantic component is important in the irrelevant speech effect. These results are consistent with Kellogg's (1996) predictions that the phonological loop is involved in the detection of spelling and typographical errors, but inconsistent with the prediction that irrelevant speech would hinder the detection of grammatical and word choice errors.

Investigations of irrelevant speech effects on reading comprehension also failed to support the role of the phonological loop as a temporary store for sentence representations (Martin, Wogalter, & Forlanon, 1988). In the initial investigation, comprehension scores declined in two conditions involving irrelevant speech compared to

a silent control. The irrelevant speech consisted of either words in a meaningful order or the same words randomly scrambled. Comprehension in the two speech conditions was not reliably different. In a second experiment, Martin et al. (1988) manipulated instrumentation (present or not) and lyrics (sung, spoken, or none) within subjects. Findings indicated that the presence of verbal material adversely affected comprehension, while instrumentation did not.

Madigan and Linton (1996) asked participants to compose two essays on a word processor, one while hearing irrelevant speech and the other in silence. Prior to the writing session, participants completed a reading span task designed by Daneman and Carpenter (1980). This reading span test is used to assess capacity by incorporating a processing and a storage component. Participants read aloud an increasingly larger set of sentences. After each set, they recalled the last word of each sentence. Madigan and Linton based the working memory span on the number of last words correctly recalled. Those who scored in the top third of the sample were classified as high capacity, while those in the bottom third were classified as low capacity.

Irrelevant speech reliably reduced the holistic quality of the essays, also causing a decline in syntactic complexity (the proportion of subordinate clauses that occur before the main verb) among high span writers. Writing fluency, as measured by word production times and pauses within selected clauses, were unaffected by the irrelevant speech manipulation. The investigators argue that the reduction in holistic quality is inconsistent with assumptions of the Kellogg model related to the relatively minor influence of the phonological loop when compared to the central executive, on writing quality. Kellogg

(1996), however, disagrees, contending that "the small effect size is consistent with the hypothesis that irrelevant speech disrupts only translating and reading" (p 69).

Ransdell, Levy and Kellogg (1977) used irrelevant speech and memory load manipulations comparing performance of writers with high and low writing span in a series of experiments. They hypothesized that irrelevant speech, linked only to translating and reading, would have a relatively small effect on fluency and quality compared to a memory load relying on central executive resources. They also expected that the number of pauses would decline when the central executive rather than the phonological loop was affected by the manipulation.

In each of three experiments, participants composed two 10-minute essays. In the first experiment, one essay was written while hearing irrelevant speech, the other in silence. In the second experiment, they wrote with or without a six digit concurrent load. In the final investigation, participants wrote one essay in the presence of unattended irrelevant speech, and one essay while they were instructed to attended to the irrelevant speech, periodically responding "yes" or "no" to questions related to either phonological, spatial or semantic characteristics of the message. Because the semantic task was positioned as more heavily dependent on central executive capacity, it was expected that decrements in performance would be greatest in this condition.

Results of the first experiment demonstrated that irrelevant speech reliably reduced fluency, and an increase in the number of pauses longer than five seconds, but did not influence the percentage of pauses at clause boundaries. Essay quality was similar in the irrelevant speech and silent conditions, an unexpected finding. The researchers suggested two possible explanations for the immunity of essay quality to the speech manipulation.

First, they considered the possibility that the phonological loop is activated only for complex sentences. Second, they raised the possibility that the articulatory loop was more intimately involved in the writing task than the phonological loop, and that irrelevant speech derived its influence via corrupting material in the store.

In the second experiment, memory load also resulted in a reliable decrement in fluency and in sentence length. Only the fluency of low span writers was adversely affected by the concurrent task. Concurrent load also altered the temporal patterns of composing. When remembering and recalling digits, participants paused longer and more often. High span writers also paused less frequently at clause boundaries. Furthermore, unlike exposure to irrelevant speech, the concurrent task also reliably reduced essay quality.

In the third experiment, attending and responding to irrelevant speech led to a reliable decrement in writing fluency, sentence length and pause frequency compared to baseline, but pause length and location were similar in both conditions. Additionally, overall writing quality did not decline in the attended speech condition, although scores of high span writers with "good sentence" instructions were adversely affected in the organization and development subgroup. The type of question answered in the attended speech condition (phonological, spatial, or semantic) did not affect any dependent measure. Of the three secondary tasks, accuracy was higher in the semantic condition than in the spatial or phonological conditions which were equivalent.

The most consistent result throughout the three experiments was the expected decrement in fluency as a result of the experimental manipulation. Neither unattended nor attended speech resulted in a quality decrement. In contrast, the six-digit concurrent load did adversely affect quality relative to a control condition. The six-digit load was also the

only task that lengthened pause duration and reduced the proportion of pauses at clause boundaries. Here, there is a trade-off between quality and fluency that involves an increase in the number of pauses rather than in their duration.

To test Kellogg's (1996) predictions of the phonological loop involvement in translating ideas into sentences (formulation) and reading text (monitoring), Marek and Levy (1996) designed a series of computer-based tasks to simulate these primary writing processes. These writing subtasks included creating sentences from groups of words (formulation), copying an existing text (execution) and proofreading (monitoring). Writers first performed each of the three tasks in silence, then repeated each task while listening to computer-generated speech. Irrelevant speech during the formulation task reliably reduced both the number of target words used in the sentences and sentence quality, a measure based on a combination of meaningfulness and technical quality. Irrelevant speech did not influence performance measures related to execution or monitoring as predicted by the model but did lend support to the role of the phonological loop in formulation.

One possible explanation for the null result found for monitoring relates to the proportion of editing versus reading in the tasks. In the proofreading task, twenty errors were embedded into approximately 150 words of text. Participants were asked not only to detect the errors, but to identify them as well, within a 5-minute time period. Beyond the obvious possibility that the results reflect a difference between proofreading someone else's work and reviewing one's own writing, the task was not designed to enable recording of the amount of time spent reading versus the amount of time spent editing. Nor did the researchers record or control how much of the selection was actually read.

The detection rate for errors ranged from 5% to 56%, but whether this primarily illustrates differing ability to identify the mistakes or differences in reading fluency remain unknown.

Another prediction of the Kellogg model suggests that loading the central executive should detract from writing fluency and quality the most, because the central executive plays a part in all three writing processes. Jeffery and Underwood (1995) conducted an experiment in which participants created sentences from information presented, with either a 0, 3, or 6 digit preload. If this construction task appropriately reflects formulation, the Kellogg model predicts that loading the central executive should disrupt its performance. Rather than an overall disruption, Jefferey and Underwood found a fluency-quality tradeoff. Although the preload actually reduced sentence initiation time, quality of the sentences, as measured by the level of idea coordination, also dropped in the preload conditions.

In a second experiment, participants copied rather than constructed sentences, again with or without a preload. In this context, sentence initiation time under a 6-digit preload was higher than in the non-preload condition. Because semantic processing is required only in the construction task, Jefferey and Underwood concluded that the decrease in sentence initiation time in their first experiment was attributable to a lack of available resources for semantic processing in the preload conditions. More generally, differences between preload and control conditions suggest that semantic processing during writing involves the central executive.

Jefferey and Underwood positioned the primary task in these experiments as constructing rather than formulating sentences. However, other writing researchers (Kellogg, 1996; Ransdell & Levy, 1996) have suggested that constructing sentences

represents one aspect of formulation in writing. Debate surrounding inconsistencies at this level underscores the difficulty involved in studying the specific components of a complex task such as writing. It raises questions concerning the relationship of the part to the whole, and calls attention to the problem of developing a satisfactory operational definition for a specific component that has been separated from its task context. Although investigations of writing at the subcomponent level are important, great difficulty surrounds this practice and some aspects of writing may not be profitably reduced to this level. Thus, this dissertation investigates essay writing as a complete task rather than breaking it down into formulation, execution, and monitoring.

Adapted Working Memory Model

The balance of this chapter closely examines the assumptions of Baddeley's working memory model and proposes an adaptation that brings working memory into closer alignment with the attention literature while simultaneously preserving its orientation toward complex language tasks. These adaptations to the working memory model have subtle implications on the dual-task methods employed by this dissertation and other studies of this nature. Before addressing these methodological implications, however, a closer analysis of working memory is needed.

There are several interesting assumptions that are commonly made about the processing capabilities of the two slave systems. First, in comparisons of visuo-spatial and phonological loads, the structural assumption implies that the relative difficulty of the secondary tasks is irrelevant because any secondary task, regardless of difficulty, will engage the visuo-spatial scratchpad or phonological loop entirely, or not at all. Therefore, a phenomenologically easy visuo-spatial task, such as identifying in which ear a sound is

played through headphones, should load the visuo-spatial scratchpad as much as a more difficult spatial task, such as mentally rotating a three dimensional object. If we assume, instead, that the slave systems represent pools of resources, then the difficulty of the secondary tasks becomes a variable of interest. This variable should be experimentally controlled because of the common finding that increasing the difficulty of a secondary task almost always results in a performance degradation in the primary task (Wickens, 1984; Navon & Gopher, 1979).

If we assume the slave systems are resource pools, then when we compare the relative effects of visuo-spatial and phonological load tasks on a primary task, it becomes important to equalize the overall difficulty of the loading tasks. Consider the implications of mistakenly assuming the slave systems are structures. If we disregard the difficulty of loading tasks, a disproportionately more difficult phonological task would disrupt the primary task of writing more than the visuo-spatial secondary task, possibly leading to the conclusion that the visuo-spatial scratchpad plays a smaller role in writing than it actually does. Thus, when comparing the contributions made by the two slave systems to a primary task under dual-task conditions, it may be more risky to assume that these components are structures rather than resource pools.

Another implication of Baddeley's theoretical assumptions arises when comparing effects across studies. Under the assumption of structural slave systems, differences in secondary task structure (including characteristics such as the frequency of response selection and execution as well as input and output modalities) will not affect the extent to which that task engages its targeted component. Resource theorists argue that just as task difficulty is likely to influence primary and secondary task interference, the frequency of

response selection and the input and response modality are likely to affect the degree to which they interfere with a primary task.

Overall, a structural assumption allows for much easier secondary task selection, but the results may be inaccurate if the visuo-spatial scratchpad and phonological loop are in fact pools of resources rather than structures. The more rigorous secondary task selection methods associated with a resource assumption are acceptable regardless of whether the visuo-spatial scratchpad and phonological loop act as structures or resources.

In light of these considerations, a new model of working memory was proposed that posits two mutually inaccessible pools of resources for verbal and visuo-spatial processing and storage such as Friedman and Polson's (1981) multiple resource model. The current model differs from Friedman and Polson (1981) in its inclusion of Baddeley's notion of a limited capacity central executive system that acts for a wide range of attentional duties including coordinating information between the visuo-spatial and verbal systems.

Experiment 1 seeks empirical support for this adapted working memory model, by testing the hypothesis that the phonological loop may be partially disrupted within subjects rather than disrupted entirely or not at all.

Summary

As a writer plans ideas, translates ideas into prose, types or handwrites sentences, and monitors all of these activities, many demands are placed on the writer's temporary storage and processing capacity. Investigations of writing at this level are fairly new, thus obligating writing researchers to turn to existing theories of cognitive limitations for a framework in which these demands may be assessed.

Theory development surrounding processing limitations has typically employed two hypothetical constructs, *resources* and *structures*. Early accounts of processing demands were explained by either resource (Kahneman, 1973) or structural (Broadbent, 1958) models, but more recently elaborate models have evolved that embody both resource and structural aspects. The two most prevalent of such models are multiple resource models (Norman & Bobrow, 1975; Wickens, 1984; Friedman & Polson, 1981) and Baddeley's working memory model (Baddeley & Hitch, 1974). Both propose divisions in visuo-spatial and verbal processing, generally in alignment with the hemispheric asymmetry literature.

Kellogg (1996) proposed a model of writing that details how specific writing processes rely on the main components of Baddeley's working memory model. Before testing the specific claims of Kellogg's model, a closer examination of working memory as a model of cognitive limitations is necessary. In particular, the assumptions of the structural nature of the phonological loop and visuo-spatial scratchpad seem outdated.

This dissertation proposes an adaptation to the working memory model whereby the phonological loop and visuo-spatial scratchpad operate as pools of mutually inaccessible resources for verbal and visuo-spatial processing and storage similar to Friedman and Polson's multiple resource model (1981). This hybrid model of working memory and multiple resources is tested in Experiment 1. Experiments 2a and 2b consider the division of labor between visuo-spatial and verbal processing and storage components, and Experiment 3 addresses the role of writing topic in the resource demands of writing.

CHAPTER 2
EXPERIMENT 1

If the phonological loop and visuo-spatial scratchpad of Baddeley's working memory model are engaged in a binary, all-or-none fashion, it follows that in a dual-task paradigm, secondary tasks of varying difficulty will have the same loading effect. This assumption is comparatively easy to test. For example, in a dual-task experiment, if two phonological or visuo-spatial secondary tasks of varying difficulty interfere equally with a primary task, then the all-or-none processing assumption is supported. Conversely, if the two phonological or visuo-spatial secondary tasks vary in the relative degree to which they disrupt primary task performance, then graded processing is supported.

Baddeley's working memory model predicts no differences in performance related to type of irrelevant speech, because speech sounds, regardless of meaning, are believed to have obligatory access to the phonological store. Those sounds are believed to engage the phonological loop entirely due to its structural nature. Inconsistent with these predictions, Jones, Miles, and Page (1990) found that meaningful speech interfered more with the detection of spelling and typographical errors in a proofreading task than the same speech played backward. However, in a second experiment, Jones et al. found no difference between the effect of reversed speech and a silent control on error detection rates, suggesting that reversed speech may not engage the phonological loop at all. It could be argued, however, that there may be so little phonemic similarity between forward and backward speech that it may not be reasonable to claim that speech played backward is

really "speech." Further, Levy and Marek (1998) report similar patterns of result in a writing study when computer-generated speech was "natural" and when the individual words in each sentence were randomly rearranged, but no changes made to their phonemic attributes.

A recent study using magnetic resonance imaging revealed that irrelevant speech played backward is processed in different areas of the brain than is forward speech, raising questions whether the phonological loop acts alone in processing speech. Baddeley's working memory model again predicts no differences in performance related to type of irrelevant speech, because speech sounds, regardless of meaning, are believed to have obligatory access to the phonological store, and are believed to engage the phonological loop entirely due to its structural nature.

Experiment 1 compares two types of irrelevant speech to test the hypothesis that the phonological loop can be differentially loaded in a dual-task paradigm. One recording was made of a passage read by the experimenter, and the other featured the same passage generated using a text-to-speech computer program. The Baddeley model predicts that accuracy on a primary memory task would be best in the absence of irrelevant speech. When either the human-generated or the computer-generated speech is delivered while participants perform another (primary) task, performance on the latter should decline, but the performance decrements should be equal for the two types of irrelevant speech. This would be so even if the materials delivered in a computer-synthesized speech generated a lesser processing load (because it lacked nuances, had reduced inflections, and so forth) than the speech produced by a human voice. In contrast, our modified model, which

anticipates such secondary tasks producing differential processing loads, would predict differential outcomes on the primary task.

Method

Participants

Twenty-six undergraduate students from the University of Florida participated in this experiment in partial fulfillment of a course requirement. One participant was excluded from the data because he or she stopped recording the recalled consonants. Participants, were neither vision nor hearing impaired.

Materials

Sets of five to nine randomly generated consonants were printed on transparencies and presentated on an overhead projector. Consonant sets contained no duplicate letters, and no two sets were identical. Participants recorded their responses on printed answer sheets during the free recall phase of the experiment.

Two tapes of irrelevant speech were recorded. One featured a children's fable read by the experimenter. The other featured the same story generated via computer running a text-to-speech program. The content and acoustic energy level of the two taped presentations was the same.

Procedure

The to-be-remembered consonant sets were shown to the participants for 10 seconds each. Participants then had 20-seconds to recall the consonants. This sequence was repeated using 15 different sets of consonants for the baseline (no irrelevant speech) and each of the experimental conditions. During the experimental conditions, participants

heard one of two types of irrelevant speech during the presentation portion of each trial. On alternate trials, the irrelevant speech was human-generated or generated via computer.

Results and Discussion

The patterns in the data are quite compelling (see Figure 1). For nearly all participants, the human-generated speech disrupted letter recall more than computer-generated speech. A within-subjects analysis of variance showed that both human-generated irrelevant speech and computer-generated irrelevant speech interfered with participants recall of consonants ($F(1,23) = 27.65$, $p<.001$ and $F(1,23) = 15.72$, $p<.001$ respectively). Recall accuracy was lower in the presence of human-generated speech than the computer-generated speech ($F(1,23) = 33.85$, $p<.001$). This pattern of results matches their subjective reports that the computer-generated speech was easier to disregard. If the phonological loop is engaged in an all-or-none fashion, it follows that the irrelevant computer-generated speech should have the same effect as irrelevant human-generated speech. These results are more consistent with the notion that the phonological loop is comprised of a pool of resources that can be engaged in a graded fashion. Further testing is needed to determine if the visuo-spatial scratchpad also operates as a resource pool rather than a structure.

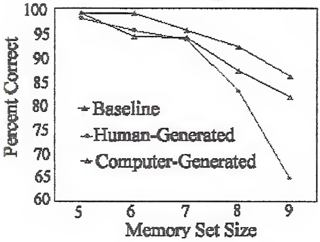

Figure 1. Retention of consonant strings as a function of memory set size and irrelevant speech condition.

Regardless of whether we assume that the visuo-spatial scratchpad operates as a pool of resources like the phonological loop, because the phonological loop operates as a resource pool, it is necessary to adopt the following criteria for selecting secondary tasks when making comparisons between these two working memory components. First, secondary tasks should be equally demanding of attentional resources. Equivalency may be accomplished by comparing secondary task performance in isolation, or by placing each secondary task in a probe-tone paradigm in which subjects perform the load task as a primary task and are interrupted occasionally by a tone to which they respond as quickly as possible. Reaction times in probe tone paradigms are typically taken as an index of the mental effort demanded by the primary task. Second, the loading tasks should not change in the degree to which they draw on controlled processes throughout the experiment. If a load can become automated over the course of the dual-task conditions, then by the most common definitions of automaticity, it no longer draws on attentional resources, thus

allowing participants to work on the primary task as if they were working under single-task conditions. Third, the tasks should have similar structural composition, requiring the same mode of input and output. Fourth, response selection and execution should occur equally often in the tasks. Finally, secondary tasks should require different strategies for their successful performance. For example, a visuo-spatial task should not be easily performed by re-coding visuo-spatial stimuli into phonological stimuli. Thus, secondary tasks should be constructed so that performance differences will emerge if participants use the same strategies for each task. The secondary task selection process for Experiment 2B serves to illustrate these selection criterion.

Once appropriate secondary tasks are selected, the rationale for dual-task studies is relatively straightforward. By selectively engaging one component of working memory in a secondary task, the primary task may then only draw on the remaining components. Thus, using a dual-task paradigm, experiment 2A investigates the contribution of verbal resources to writing in a dual-task paradigm, while experiment 2B investigates the contribution of visuo-spatial resources to writing. Given the adaptations we have made to the working memory model, comparisons of the relative involvement of verbal and visuo-spatial processing can be made across these two experiments by adhering to the secondary task selection criteria described above.

CHAPTER 3
EXPERIMENT 2

Experiment 2A

Most resource models (Wickens, 1984; Friedman & Polson, 1981) and working memory theories (Baddeley & Hitch, 1974) acknowledge a division in processing for verbal and visuo-spatial tasks, in alignment with the literature on hemispheric differences. Generally, visuo-spatial processing is localized to the right hemisphere while verbal processing is identified with the left hemisphere.

Brooks (1968) demonstrated a clear dissociation of verbal and visuo-spatial processing in an experiment were participants were presented with a block capital letter with the bottom left hand corner marked with a star. Participants were asked to look away from the letter and, holding it in memory, to go around the letter clockwise from the star responding "yes" if the corner in question pointed outward or "no" if the corner pointed inward. Hence for the block letter F, the correct responses would be "yes, yes, yes, yes, no , no , yes, yes, no." Brooks also developed a verbal task where participants were presented with a sentence like, "A bird in hand is not in the bush". Participants were asked to hold this sentence in memory, and then successively categorize each word as either a noun (in which case participants would respond "yes"), or a verb ("no"). Hence, for that particular sentence the correct sequence would be "no, yes, no, yes, no, no, no, no, yes". Brooks used two methods of responding, either spoken or manual (this involved pointing to a series of yeses or nos scattered irregularly down the response sheet). He observed a

clear interaction between type of memory task and mode of response, with the visual letter task being performed more accurately when the response was spoken than when it involved pointing, while the reverse was the case for the sentence task. This finding demonstrates the interference of tasks that share similar processes, and points to separate systems for verbal and visuo-spatial memory.

Subsequent selective interference effects have been observed: (a) Concurrent visuo-spatial pursuit tracking disrupted performance on Brook's (1968) spatial task, but not on a corresponding abstract task (Baddeley, 1975); (b) A verbal task interfered with right hand dowel balancing (Kinsbourne & Hicks, 1978); and (c) a spatial task interfered with left hand dowel balancing (McFarland and Ashton, 1978). Also, in the perceptual domain, Moscovitch and Klein (1980) observed that recognition performance was more impaired when two spatial targets were presented simultaneously (a face and a random polygon), than when a spatial and a verbal target were presented simultaneously.

EEG research supports the intuition that writing, like other verbal tasks, is supported by the left hemisphere. Gallin & Ornstein (1972) set out to select areas of the brain that the split-brain and brain lesion research had shown were involved in different tasks, and to record the brain's electrical activity while a person was doing these tasks. In general, they found that ordinary people, doing ordinary activities, turned on and off the two sides of their brain appropriately. Specifically, Gallin & Ornstein (1972) reported that the right hemisphere showed more alpha activity than the left while writing a letter and the left hemisphere showed more beta activity. While the person was arranging blocks, the left hemisphere showed more alpha than the right side, and the right hemisphere showed more beta waves. So when people write, they turn on the left hemisphere and turn off the right

side of the brain. While arranging blocks in space, they turn on the right side and turn off the left hemisphere.

Baddeley (1993) investigated the working memory demands of chess by selectively disrupting components of working memory in a dual-task paradigm. Two groups of expertise were compared: weak club players formed the basic group and an advanced group was comprised of expert chess players with Elo gradings ranging from 130 to 240. Participants were required to memorize and recall chess positions as a primary task, while performing one of three secondary tasks or a control condition where no concurrent activity was performed. To disrupt the phonological loop, participants were given a secondary task that required them to utter the word "the" at the rate of one per second (articulatory suppression). The visuo-spatial scratchpad was disrupted by requiring participants to tap the keypad of a computer at a one-second rate following a fixed order. Random letter generation, again at a one-second rate, was required to disrupt the central executive component of working memory. Overall, performance in the two groups differed greatly, but the pattern of interference was equivalent, with articulatory suppression had little effect, while both finger tapping, and random letter generation produced greater disruption. These findings suggest that verbal processes play little or no role in memory for chess positions compared to the role of visuo-spatial or central executive processes.

Several criticism can be made of Baddeley's dual-task methods in the study of chess. Because participants performance was not measured on any of the secondary tasks there is no evidence that participants performed these tasks as they were instructed. Participants may simply have slowed or even stopped performing the secondary task as

primary task demands increased. Additionally, it is possible that participant's performance of these tasks became automatic, thus requiring little or no resources. These secondary tasks implicitly assume all-or-none processing of the phonological loop, visuo-spatial scratchpad and the central executive because no attempts were made to ensure that these tasks are equally demanding.

The purpose of the present experiment was similar to Baddeley's (1993) investigation of the working memory requirements of chess, but instead of chess, this study assess the contributions of the phonological loop to essay writing in a dual-task paradigm. Writing researchers have addressed this issue by employing irrelevant speech manipulations while measuring essay quality and fluency (Ransdell & Levy, 1998; Ransdell, Levy, & Kellogg, 1997), proofreading ability (Jones, Miles, Page, 1990), temporary storage of sentence representations (Martin, Wogalter, & Forlanon, 1988), and creating sentences from groups of words, proofreading, and copying text (Marek & Levy, 1996).

Because the long-term research goal was to compare phonological loop (experiment 2A) and visuo-spatial scratchpad (experiment 2B) contributions to writing, a new secondary task was needed which, unlike irrelevant speech, required measurable responses from the participant. A signal detection paradigm (Green & Swets, 1966) paradigm was implemented because it would allow for easy comparison of performance to a similar visuo-spatial secondary task. Signal detection is a well-established method used by engineers and by psychophysicists for estimating an observer's discriminative capacity or sensitivity to a signal independent of the observer's response bias. The measure of sensitivity is a pure number represented by the symbol, $\underline{d}'$ which is based on the

participants' number of hits and false alarms. The greater the value of d', the better the individual's performance.

Additional efforts were necessary to assure that this secondary task did not become automatic. Dual-task conditions were designed so the data could be parted into five-minute epochs for which individual d' scores could be calculated. Thus, patterns of d' scores could be inspected qualitatively on an individual basis and participants who showed dramatic changes in secondary task performance over time could be eliminated from the study. No participants were excluded from this study based on this information. Figure 2 illustrates the average secondary task performance and the percentage of writing as a function of these five-minute epochs.

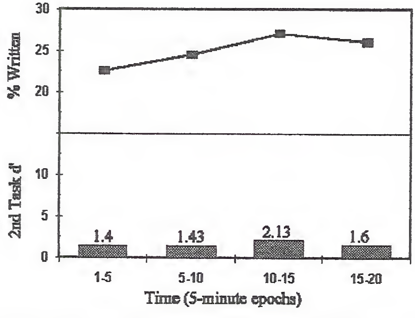

Figure 2. Average percentage written and dual task performance as a function of time.

Method

Participants

Forty-one University of Florida general psychology students participated in this study. All participants reported to be proficient touch typists (avg. typing speed was 32 wpm) and had experience interacting with a computer using a mouse.

Materials and Apparatus

Participants wrote essays on 2 open-ended topics, "The perfect job" and "The greatest high" using a Windows-based word processor developed especially for this research effort. The program supported basic functions of text entry, cutting and pasting, and mouse control at the point of insertion. The program also enabled the presentation of the secondary task stimuli (directional symbols) in a large (120 point) sans serif font displayed to the left of the text composition window. The characters subtended approximately 3 degrees of visual angle and were readily identifiable from the writers' peripheral vision.

Procedure

Participants first completed a 2-minute typing test in which they were asked to transcribe as quickly as possible text that appeared on their screens. Next, they spent 20 minutes writing an essay on one of the two topics. Participants were given verbal notice 5 minutes before their time expired.

Participants next performed a task designed to load the phonological loop under single-task conditions for 5 minutes. This task was designed to load the phonological loop, but not the visuo-spatial scratchpad. During this task, a single letter or a single digit was shown for 5 seconds. At the end of this period, the visible stimulus was erased and

replaced by another single character. The characters typically alternated between letters and digits. The participant's task was to indicate – by pressing the mouse button – whenever the category (letter or digit) remained the same from one presentation to the next (i.e. two consecutive letters or numbers). A response was required, on the average, twice per minute on a variable interval schedule. Consecutive letters and consecutive digits occurred equally often. If participants responded correctly a green circle appeared instead of the next character, but if they missed an opportunity to respond correctly a red circle appeared instead of the next character. False alarms did not disrupt the sequence of character presentation, and no feedback was given to indicate a false alarm had been made.

In the final, dual-task phase of the experiment, participants wrote for 20 minutes on whichever topic they had not already addressed earlier under single-task conditions. At the same time, they simultaneously performed the phonological loading task that they had just finished. Instructions for the loading task, stimuli presentation rate, and method of responding were identical to the single-task conditions. Participants were instructed to perform both tasks to the best of their ability. To maintain interest in the task, the research promised that the person who performed the best overall would win $100.

Results and Discussion

Document quality was assessed on a 6-point scale using the essay-sort method (Madigan, Johnson, & Linton, 1994) where two independent raters sorted essays first into 3 categories of quality, and then rated essays as high or low quality within category (inter-rater reliability = 88%). Document fluency was measured by the number of words

generated per minute. A signal detection paradigm (Green & Swets, 1966) was employed in the phonological secondary task.

As illustrated in Figure 3, performance in the present experiment deteriorated significantly from single to dual-task conditions on all measures. Words produced per minute dropped 21% ($\underline{t}$ (42) = 7.19, $\underline{p}$<.001) and the quality of the essays declined 12.3% ($\underline{t}$ (42) = 2.71, $\underline{p}$=.01) with the addition of the phonological loop secondary task. Most compelling was a 60% decrement in d' associated with the addition of the secondary task ($\underline{t}$(42) = 8.91, $\underline{p}$ <.001).

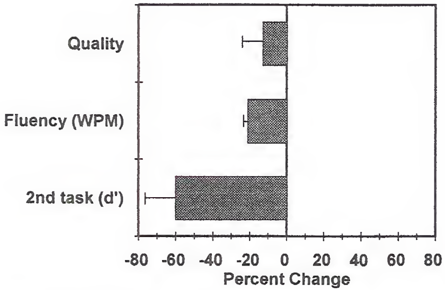

Figure 3. Decrement in quality, fluency, and secondary task $\underline{d}$' from single to dual-task phonological load conditions.

Kellogg's (1996) predictions for the involvement of the phonological loop in writing were that this component would play a strong role in monitoring, particularly in the detection of spelling and typographical errors. Also, the phonological loop should

have a minor influence on writing quality relative to the central executive, but more influence on quality than the visuo-spatial scratchpad.

Decrements in quality associated with the phonological secondary task seem to conflict with Levy, Ransdell & Kellogg (1997) who failed to find an effect of irrelevant speech on essay quality. Inconsistencies here can be explained by the greater demands of the letter matching task due to response selection and execution stages that were required. It is important to keep in mind that the primary purpose of this experiment is the eventual comparison to the effects of a visuo-spatial loading condition, and therefore the response selection and execution stages are necessary, and will algebraically cancel each other out when that comparison is made.

Researchers using an irrelevant speech manipulation have observed disruptions in the detection rate for non-contextual errors (Jones, Miles, and Page, 1990), diminished comprehension (Martin, Wogalter, & Forlanon, 1988), lower holistic quality of essays and diminished syntactic complexity as measured by the proportion of subordinate clauses that occur before the main verb (Madigan & Linton, 1996).

The present experiment supports Ransdell, Levy & Kellogg's (in press) finding that irrelevant speech reliably reduced fluency as measured by words per minute. Madigan and Linton (1996), however, found no effect of irrelevant speech on fluency as measured by word production times and pauses within selected clauses. This calls into question the relationship between different measures of writing fluency.

Further questions involve how a visuo-spatial secondary task will effect essay quality, fluency, and d' scores compared to the phonological secondary task observed in

this experiment 2B describes the selection and effects of a visuo-spatial secondary task, followed by the combined analysis of experiments 2a and 2b.

Experiment 2B

Because of the impressive amount of research on the effects of irrelevant speech on the variety of tasks discussed earlier, the focus of considerable recent work in writing has also focused on variables that might influence the engagement of the phonological loop. The role of visuo-spatial processing in writing has received very little attention compared to that of the phonological loop (Dinet & Passerault, 1998; Levy, White, & Lea, 1998).

Kellogg (1996) claimed that visuo-spatial resources are involved in planning, particularly when writers plan by visualizing ideas, organizational schemes, supporting graphics, appearances of the orthography and layout. In one of the only studies investigating the role of the visuo-spatial scratchpad in writing, Ransdell, Levy, & Kellogg (1997) had participants write one essay in the presence of unattended irrelevant speech, and one essay while they were instructed to attend to the irrelevant speech periodically responding "yes" or "no" to questions related to either phonological, spatial or semantic characteristics of the message. The type of question answered in the attended speech condition did not affect any dependent measure. One interpretation of this lack of findings is that the combination of making judgements requiring a response on irrelevant speech may have simultaneously loaded the phonological loop (with irrelevant speech), the central executive (by requiring response selection and execution) and then either the phonological loop (phonological judgements) or the central executive (semantic judgements) again or the visuo-spatial scratchpad (with spatial judgements).

In the present experiment, we use the methodology underlying Experiment 2A to focus on how processing in the visuo-spatial scratchpad influences writing. The hypothesis was that a visuo-spatial task, like the phonological task in the previous experiment, would cause a significant decrement in writing quality and fluency. Additionally, when comparing the dual-task performance of a visuo-spatial task and writing to dual-task performance of a phonological task and writing (Experiment 2A), dual-task performance would be better in the visuo-spatial condition.

In order for performance here to be compared to Experiment 2A, a secondary task was needed to engage the visuo-spatial scratchpad in a signal detection paradigm where no significant differences exist between the visuo-spatial and phonological single task d' scores. Additionally, this visuo-spatial secondary task would also need to be designed so that d' scores could be calculated for each 5-minute epoch, to assess whether that task became automated. Figure 4 illustrates the average secondary task performance and the average percentage of writing as a function of these five-minute epochs.

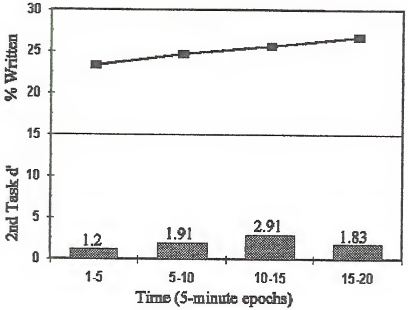

Figure 4. Average percentage written and dual-task performance as a function of time.

Stimulus presentation modality and rate and the rate of responding needed to be equivalent for the visuo-spatial and the phonological secondary tasks. Additionally, the visuo-spatial secondary task had to be constructed so that performance differences would emerge if participants encoded the stimuli verbally as they did in the phonological loop secondary task.

Method

Participants

Forty-four University of Florida general psychology students participated in this study. All participants reported to be proficient typists (avg. typing speed was 34 wpm) and had experience interacting with a computer using a mouse.

Apparatus and Materials

Participants wrote essays on 2 open-ended topics, "The perfect job" and "The greatest high". They used a Windows-based word processor written especially for this research effort. The program supported basic functions of text entry, cutting and pasting, and mouse control at the point of insertion. The program also enabled the presentation of the secondary task stimuli (directional symbols) in a large (120 point) sans serif font displayed to the left of the text composition window. The characters subtended approximately 3 degrees of visual angle and were readily identifiable from the writers' peripheral vision.

Procedure

Participants first completed a 2-minute typing test in which they were asked to transcribe as quickly as possible text that appeared on their screens. Participants then wrote an essay for 20 minutes on one of the two topics. Half wrote on one topic, while the other half wrote on the other. Participants were given notice 5 minutes before their time expired.

Participants next performed a visuo-spatial task for 5 minutes. This task was designed to load the visuo-spatial scratchpad but not the phonological loop. Rather than letters and digits, the computer displayed equal-sized arrows that pointed up, down, left, or right. The participants' task was to maintain in memory a representation of an x, y coordinate system and an imaginary placeholder at the 0,0 coordinate. They were instructed to move the imaginary placeholder one standard, but arbitrary, unit of distance in the direction of the arrow presented. They were further instructed to click the mouse button any time the placeholder moved away from either axis and then returned to either

axis. A new arrow was presented every 5 seconds and, on the average, a response was required twice per minute. Crossings of the x- and y-axis occurred equally often. If participants responded correctly a green circle appeared instead of the next arrow, but if they missed an opportunity to respond correctly a red circle appeared instead of the next arrow. False alarms did not disrupt the sequence of arrow presentation, and no feedback was given to indicate a false alarm had been made.

In the final, dual-task phase of the experiment, participants wrote for 20 minutes on whichever topic they had not already addressed earlier as the primary task. At the same time, they simultaneously performed the secondary loading task that they had just finished. Instructions for the loading task, stimuli presentation rate, and method of responding were identical to the single-task conditions. Participants were instructed to perform both tasks to the best of their ability. Again, to maintain interest in the task, the researcher promised that the person who performed the best overall would win $100.

Results and Discussion

Like experiment 2A, document quality was assessed on a 6-point scale using the essay-sort method (Madigan, Johnson, & Linton, 1994) where two independent raters sorted essays first into 3 categories of quality, and then rated essays as high or low quality within category (inter-rater reliability = 84%). Document fluency was measured by the number of words generated per minute. A signal detection paradigm (Green & Swets, 1966) was employed in the phonological secondary task.

The secondary task met all of the criteria established for secondary task selection, most important of which was that there was no significant difference between visuo-spatial and phonological d' scores under single task conditions (3.50 and 4.09 respectively). If the

visuo-spatial task had been re-coded into a verbal task then a phonological representation of the presented arrows (up, up, right, down, up, left, etc) would need to be maintained in working memory. If this had been the case then we would have expected performance to be much worse compared to the phonological secondary task because participants would need to hold more information (up to 10 chunks) in memory than they would on the verbal secondary task where only the last character needed to be remembered. If they instead adopted a visuo-spatial coding strategy and stored the location of a mental placeholder as they were instructed, then only one chunk needed to be maintained in memory and single-task performance would be equivalent to the phonological secondary task. No significant differences were found between the phonological d' (4.09) and the visuo-spatial d' (3.5) under single task conditions.

Results indicated that much like experiment 2, performance in the present experiment deteriorated significantly from single to dual-task conditions on all measures (see Figure 5). Words produced per minute dropped 13% (t (39) = 3.17, $p<.01$) and the quality of the essays declined 13.6% (t (39) = 2.95, $p<.01$) with the addition of the phonological loop secondary task. A 44% decrement was observed in d' comparing single to dual-task conditions ($t(39) = 6.01$, $p <.001$).

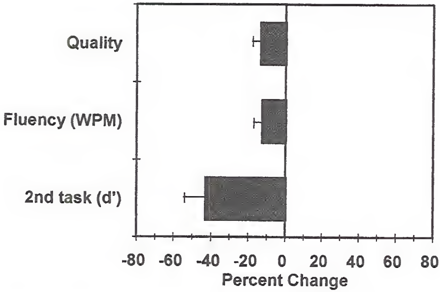

Figure 5. Decrement in quality, fluency, and secondary task d' from single to dual-task visuo-spatial load conditions.

Combined Analysis of Experiments 2A and 2B

As Figure 6. shows, selectively engaging either component of working memory reliably deteriorated fluency, quality and secondary task performance. Table 3 lists means and standard deviations for fluency, quality and secondary task d' scores under single and dual-task conditions. Writing fluency slowed significantly overall, $F(1, 81) = 49.06$, $p < .001$, and as Kellogg's model anticipates, there was a significant interaction between the component of working memory that was loaded and the testing conditions (either single or dual-task), indicating that the phonological secondary task disrupted fluency more than the visuo-spatial secondary task, $F(1,81) = 3.99$, $p = .04$. Interestingly, the d' measured during the phonological secondary task declined much more than during the visuo-spatial scratchpad, as reflected in the interaction between loading task and the testing conditions, $F(1, 81) = 5.79$, $p < .01$. The decrement in d' associated with the dual-task for the visuo-

spatial group was 44%. For the phonological group, the d' fell 60%. Although quality was not affected more by one working memory load than another, both fluency and d' scores deteriorated more in the pairing of the phonological task with writing than in the pairing of the visuo-spatial task and writing. Despite the equal degradation in writing quality, these results suggest greater difficulty in timesharing writing with a phonological task than a with visuo-spatial task which is consistent with Kellogg's (1996) predictions.

Table 3.

Means and standard errors for d', writing speed, and writing quality scores for the single and dual visuo-spatial and phonological tasks.

Measure	Visuo-spatial Single Task	Visuo-spatial Dual-task	Phonological Single Task	Phonological Dual-task
d'				
Mean	3.50	1.96	4.09	1.64
SD	1.72	0.85	1.73	0.67
WPM				
Mean	14.7	12.8	16.2	12.8
SD	0.79	0.70	0.62	0.57
Quality				
Mean	3.16	2.73	3.18	2.79
SD	1.04	.95	0.92	0.82

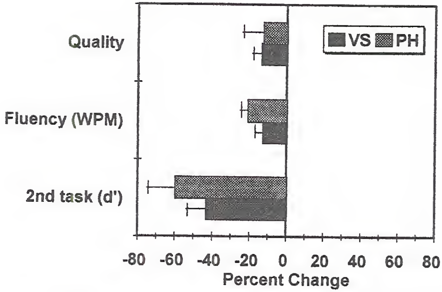

Figure 6. Decrement in quality, fluency, and secondary task d' from single to dual-task conditions separated by resource loading condition.

These findings support the recent trend toward multi-component models of working memory, and in particular those that distinguish between visuo-spatial and verbal resources. It is clear that these results do not support the undifferentiated class of models that dominated early writing process research. Undifferentiated models would predict that equally demanding secondary tasks would be equally interfering with the writing primary task. Our phonological secondary task clearly interfered more than the visuo-spatial secondary task despite no single-task performance differences (in fact, trends in the single-task data indicated that the visuo-spatial task was slightly more difficult than the phonological task although differences were not significant).

In the future this line of research may be extended to the subprocess level of writing where we can investigate the demands that formulating, executing and monitoring place on the visuo-spatial scratchpad and phonological loop. These future investigations

will employ methods based on a resource capacity assumption of phonological loop and visuo-spatial scratchpad processing, and will include the methods for selecting secondary tasks that we specified earlier.

CHAPTER 4
EXPERIMENT 3

Experiments 2a and 2b lend support to the notion that visuo-spatial processes are active in writing, because of the size of decrements in writing quality and fluency observed in the presence of the visuo-spatial secondary task. However, questions about the specific role of visuo-spatial processes in writing remain unanswered. Kellogg (1996) suggests that planning may draw on visuo-spatial processes when ideas, organizational schemes, or appearances of the orthography and layout are visualized. The current experiment tests Kellogg's claims by manipulating the writing topic so that one of two similar essays requires more visuo-spatial processing than the other. Under dual-task conditions designed to load the visuo-spatial scratchpad, a visuo-spatial writing topic should be more difficult than a similar non visuo-spatial writing topic.

Some clues about the involvement of visuo-spatial processes in language tasks come from in the hemispheric asymmetry literature. Ornstein, Herron, Johnstone and Swencionis (1979) compared the EEG measure of brain activity of participants while they read either technical passages or folktales. The left hemisphere acted the same with the technical material and the folktales. However, the right hemisphere activated while the subjects read the folk stories, but it did not while they read the technical material. Ornstein et al., explain that technical material is almost exclusively imageless, while stories generate lots of images, and that "the sense of a story emerges through style, images, and feelings" (Ornstein, 1998, p. 73). Thus, reading may rely on the visuo-spatial processes associated

with the right hemisphere as well as the left hemisphere, depending on what is being read.

In another investigation of visuo-spatial information within language, Atwood (1971) carried out an experiment in which participants heard either highly imageable phrases such as "Nudist devouring bird", or highly abstract phrases such as "The intellect of Einstein was a miracle." Each phrase was followed by a simple classification task presentated either audtitorily or visually. Atwood reported a tendency for the imageable phrases to be disrupted much more by processing the visually presented digits, while the abstract sentences were disrupted more by auditory processing.

The current experiment tests Kellogg's (1996) claims that visuo-spatial resources are involved in planning, particularly when writers plan by visualizing ideas. This experiment tests this claim by comparing writing on two different topics. Both topics are descriptive in nature, but one requires visualization and spatial memory while the other does not. Quality and fluency are expected to be better on the non visuo-spatial topic under dual-task conditions, but no differences are expected under single-task conditions.

Method

Participants

Fifty-eight general psychology students, from the University of Florida participated in this experiment for which they received credit towards course requirement. To assess differences in quality or fluency associated only with topic, the first twenty of these students wrote two essays, one on each topic under single-task conditions. The remaining thirty-eight students participated in all phases of the experiment except single-task writing conditions. All reported that they were comfortable interacting with computers with a mouse and were proficient typists.

Apparatus and Materials

Participants were each seated at an IBM-compatible 586 computer running Microsoft Windows 95 with 15 inch monitors. Stimuli in all phases of the experiment were created in Microsoft Visual Basic version 4. Two descriptive essay topics were employed by this study. One essay required participants to describe the spatial layout of the house they grew up in, while the other topic required them to describe the perfect job.

Procedure

There were 4 phases to this experiment; A typing test, single-task performance of a visuo-spatial task, and two dual-task conditions. All phases of this experiment required participants to interact with a computer.

In order to assess typing proficiency, participants were given 2 minutes to duplicate a passage of text as quickly as the could. The visuo-spatial monitoring task from experiment 2 was used here for 5 minutes. This task was designed to load the visuo-spatial scratchpad but not the phonological loop. The computer displayed equal-sized arrows that pointed up, down, left, or right. The participants' task was to maintain in memory a representation of an x, y coordinate system and an imaginary placeholder at the 0,0 coordinate. They were instructed to move the imaginary placeholder one standard, but arbitrary, unit of distance in the direction of the arrow presented. They were further instructed to click the mouse button any time the placeholder moved away from either axis and then returned to that axis. A new arrow was presented every 5 seconds and, on the average, a response was required twice per minute. Crossings of the x- and y-axis occurred equally often.

During each of two 10-minute dual-task phases of the experiment, participants simultaneously performed the visuo-spatial task and wrote an essay on a given topic. The essay topics "The perfect job" and a "The house you grew up in" were counterbalanced to assess practice effects associated with order.

Results and Discussion

Essay quality was again assessed on a 6-point scale using the essay-sort method (inter-rater reliability = 84%) (Madigan, Johnson, & Linton, 1994). Essay quality was also assessed by Flesch-Kincaid grade level calculations which are based on average number of words per sentence and the average number or syllables per word. Document fluency was measured by the number of words generated per minute, and a signal detection paradigm (Green & Swets, 1966) was employed in the visuo-spatial secondary task. Additional calculations of the percentage of sentences that contained spatial information were calculated for the essays written on the visuo-spatial topic under both single and dual-task conditions.

As in experiments 2a and 2b, dual-task conditions here were first partitioned into 2.5 minute epochs for which individual d' scores were calculated. Again, patterns of d' scores indicated that secondary task performance was not automated over time.

As illustrated in Table 2, secondary task d' scores were not significantly different between the two writing topic conditions under either single or dual-task conditions, and unlike experiments 2a and 2b, no decrement in d' scores was found when comparing single to dual-task conditions (see figure 7). Failure to replicate the d' decrements observed in experiments 2a and 2b may indicate differences in the research participant pool from Summer to Spring semesters.

Table 2

Means and standard deviations for d' scores for the single-task and dual-task with visuo-spatial and non-visuo-spatial writing topics.

Measure	Single-Task	Visuo-spatial Topic Dual-task	Non-visuo-spatial Topic Dual-task
d'			
Mean	4.36	3.70	3.73
SD	4.19	4.11	3.98

As expected, no quality, grade level, or fluency differences were found between topics under single-task conditions (see Table 3) suggesting that there were no pre-existing differences associated with the two topics.

Table 3

Means and standard deviations for Flesch-Kincaid grade level assessment and words per minute for each writing topic under single and dual-task conditions.

Measure	Visuo-spatial Essay Single-Task	Non- Visuo-spatial Essay Single-Task	Visuo-spatial Essay Dual-task	Non- Visuo-spatial Essay Dual-task
Grade Level				
Mean	9.48	9.32	4.73	6.99
SD	2.06	2.11	1.68	1.9
Quality				
Mean	3.25	3.22	2.65	2.78
SD	.96	.92	.87	.88
WPM				
Mean	18.8	19.7	15.1	16.5
SD	.43	.45	.36	.47

As in experiment 2A and 2B, quality, fluency, and grade level measures were disrupted by the addition of the secondary task (F (1,56) = 13.46, $p < .001$), (F (1,56) =

10.23, $p < .001$) and (F (1,56) =63.19, $p<.001$) respectively (see Figure 7). The pattern of results for quality and fluency under dual-task conditions indicated differences between topics in the direction hypothesized, but those trends did not reach significance. Flesch-Kincaid grade level calculations did support the hypothesis. The non visuo-spatial topic grade levels (avg. = 6.99) were significantly better than grade levels for the visuo-spatial topic (avg. = 4.73) under dual-task conditions as evidenced by a significant interaction between topic and task condition (F (1, 56) = 13.40, $p = .001$).

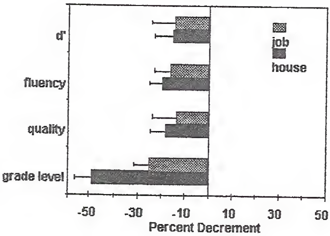

Figure 7. Dual-task decrement in secondary task $\underline{d}$', fluency, quality ratings, and Flesch-Kincaid grade level assessments.

Although the expected differences between quality and fluency of the two topics under dual-task conditions were not observed, the grade level assessment suggests greater interference between the secondary task and writing on the visuo-spatial topic. Trends in the quality and fluency ratings were consistent with the hypotheses, but differences did not reach significance. One explanation for higher than expected visuo-spatial essay quality was that writers might have avoided visuo-spatial planning in the presence of a visuo-

spatial secondary task. To test this possibility, the percentage of sentences that contained some visual or spatial description was calculated. Sentences such as, "if you walk into the master bedroom, on the right, after the closet, is a sink, then a bathroom" were considered spatial sentences whereas sentences such as "My house was full of nice furniture that I liked to play around" were considered non-spatial. The visuo-spatial essay written in the presence of the secondary task contained significantly fewer spatial description sentences than essays written on the same topic in isolation (56% Vs 70% respectively) (t (56) =1.9, p= .03). More research is needed to control for the possibility that a phonological secondary task might have the same effect, but this result suggests that the presence of the secondary task changed the way the writers addressed the topic.

CHAPTER 5
GENERAL DISCUSSION

Experiment 1 illustrated the varying capacity in the phonological loop which clearly presents explanatory difficulties for classes of models, including Baddeley and Hitch's (1974) working memory, that postulate structures such as a phonological loop or a visuo-spatial scratchpad to operate as binary, all-or-none mechanisms. Instead, our data are compatible with an important, but seemingly subtle, variation that conceptualizes these mechanisms as pools of resources that can operate in a continuous or graded fashion. The distinction is important for writing theorists and researchers because it may help them to make closer contact with colleagues who are exploring other aspects of human cognitive processing, including speech production, language comprehension, or problem solving.

Questions of the processing nature of the visuo-spatial scratchpad remain unresolved, but the methodology described in Experiment 1 lends itself well to this question. Under dual-task conditions, if two visuo-spatial secondary tasks of varying difficulty interfere equally with a primary task, then the all-or-none processing assumption is supported. On the other hand, if the two visuo-spatial secondary tasks vary in the relative degree to which they disrupt primary task performance, then graded processing is supported.

Postulating that the visuo-spatial scratchpad and phonological loop comprise pools or resources necessitates new guidelines for selecting secondary tasks. Five guidelines are especially important for comparisons of visuo-spatial and verbal resource involvement: 1.

Secondary tasks should be equally demanding of attentional resources; 2. The loading tasks should not change in the degree to which they draw on controlled processes throughout the experiment; 3. The tasks should have similar structural composition, requiring the same mode of input and output; 4. Response selection and execution should occur equally often in the tasks; and 5. Finally, secondary tasks should require different strategies for their successful performance.

Experiments 2a and 2b followed the secondary task guidelines described above. Single-task d' scores were not significantly different between visuo-spatial and verbal loading tasks, therefore suggesting that these tasks are equally demanding. To assure that secondary tasks did not become automatic, 20-minute dual-task conditions were broken down into 4 five-minute epochs for which d' scores were calculated. Patterns of d' scores were inspected qualitatively on an individual basis with the intention of discarding participants from the study if their performance changed over the course of the dual-task conditions. No participants were excluded from this study based on this information. Stimulus presentation modality and rate and response rate were identical for the visuo-spatial and the verbal secondary tasks. Secondary tasks were constructed so that performance differences would emerge if participants used the same strategies for each task.

Experiment 2A reported a significant decrement in essay quality and fluency associated with loading the phonological loop. These decrements in quality are consistent with disruptions in comprehension in the presence of irrelevant speech (Martin, Wogalter, & Forlanon, 1988), and lower holistic quality of essays and diminished syntactic complexity as measured by the proportion of subordinate clauses occurring before the

main verb (Madigan & Linton, 1996). On the other hand, these findings seem to conflict with Ransdell, Levy & Kellogg (in press) where an irrelevant speech manipulation reportedly had no effect on essay quality. Inconsistencies here may point to differences between irrelevant speech manipulations and the letter matching task employed in Experiment 2A. In particular, response selection and execution stages required by the letter matching task are likely to place greater demands on working memory, thus having a greater impact on primary task performance.

Fluency decrements reported in Experiment 2A support Ransdell, Levy, & Kellogg's (1997) finding that irrelevant speech reliably reduced fluency as measured by words per minute. Madigan and Linton (1996) however, found no effect of irrelevant speech on fluency as measured by word production times and pauses within selected clauses. This raises questions concerning the reliability of different fluency measures.

Experiment 2B tested the hypothesis that a visuo-spatial secondary task equal in difficulty to the phonological secondary task would be easier to time-share with writing. This hypothesis is based on Kellogg's (1996) claims that writing depends more on the phonological loop than on the visuo-spatial scratchpad. Results indicated that much like Experiment 2, quality and fluency deteriorated significantly with the addition of the visuo-spatial secondary task. Despite equal degradation in writing quality and fluency, results suggested greater difficulty in timesharing writing with a phonological task because the phonological secondary task performance fell much more drastically than the visuo-spatial secondary task performance.

Experiments 2a and 2b therefore indicate that writing draws more on verbal resources than visuo-spatial resources, which is consistent with EEG studies of writing

(Ornstein, Herron, Johnstone and Swencionis (1979). These results support a multicomponent resource model of writing that specifies a division of visuo-spatial and verbal resources instead of one undifferentiated pool of resources (Kahneman, 1973). Undifferentiated models predict that equally demanding secondary tasks would be equally interfering with a primary task. Based on single-task performance measures, our visuo-spatial and phonological tasks were statistically equivalent, nevertheless, when the loading tasks were performed at the same time that participants engaged in text production, the phonological task clearly interfered more than the visuo-spatial task.

Support for a role of visuo-spatial working memory in writing is suggested by the high interference between writing and a visuo-spatial task. However, as pointed out earlier, interference could also be due to the response selection and execution aspects of the visuo-spatial task. How can response selection and execution be teased out of a visuo-spatial task without loosing some performance measure for that task? One possibility involves postponing response selection and execution stages until after the dual-task conditions are completed. For example, visuo-spatial stimuli may be presented as a secondary task, and memory for the presented information can be tested after completion of the dual-task condition, thus avoiding response selection and execution stages during the dual-task condition. The disadvantage to this postponement of judgements is that this type of visuo-spatial task shifts the emphasis from processing to storage, and this distinction is not yet fully understood. Klapp and Netick (1988) report interference between two processing tasks and two memory storage tasks, but not between a processing and storage task suggesting that processing and storage resources are divided. Wickens (1984) does not recognize storage and processing as an important distinction

though. Other methods of loading working memory in specific ways and then examining their effects on the output of one or more systems or basic processes should be explored further. One such method is embodied in the approach taken by Experiment 3.

Support for multicomponent resource models represents new trend in writing research. Until recently, process-oriented writing research has been theoretically rooted in accounts of attention based on undifferentiated capacity such as the model advanced by Kahneman (1973). Writing research progressed under single capacity models as evidenced by the influence of the Hayes & Flower (1982) model of writing and successful development of computer-aided writing tools (Kellogg, 1994; Lea, Levy & Marek, 1995; Lea, Rosen, Levy, Marek & Ransdell, 1995). Recent considerations of the role of limited cognitive capacity in writing necessitate the more specific models of cognitive limitations such as Baddeley's working memory model and multiple resource models.

Experiment 3 took a new approach to test specific hypotheses about the role of visuo-spatial processes in writing. Specifically, this experiment tested Kellogg's (1996) claims by manipulating writing topic so that one of two similar essays required more visualization or spatial processing than the other. In a dual-task paradigm designed to load the visuo-spatial scratchpad, the more visuo-spatial of the two topics should be more difficult to timeshare.

Although significant differences were not found between fluency and quality, the pattern of results matched our expectations. Significant differences in Flesch-Kincaid grade level assessments supported the hypothesis indicating that more visuo-spatial resources were required by the visuo-spatial writing topic. These findings are consistent with Ornsetien, Herron, Johnstone, and Swencionis' (1979) findings that the right

hemisphere EEG is more active in reading passages containing imagery than technical passages, and Atwood's (1971) finding that imageable phrases interfered more with a visual than an auditory secondary task.

Visuo-spatial essay quality was higher than expected, raised concerns that participants may have preserved essay quality by avoiding visuo-spatial planning by focusing on non-spatial aspects of the house they grew up in. Closer examination of the visuo-spatial essays revealed a significantly higher percentage of sentences devoted to spatial description under single-task conditions. Further testing is needed to clarify whether this effect is due to the visuo-spatial nature of the secondary task.

We expect this line of research to extend to the subprocess level of writing, enabling investigations of the demands that formulating, executing and monitoring place on the visuo-spatial scratchpad and phonological loop. These future investigations will employ methods based on a resource capacity assumption of phonological loop and visuo-spatial scratchpad processing, and will include the methods for selecting secondary tasks that we addressed earlier.

Current research in our laboratory (Levy, White, Lea, & Ransdell, 1998) extends the methodologies introduced here to evaluate other claims from current working memory-based models of text production. For example, we have recently devised a way to overcome the inherent confounding in Experiments 2 and 3 between the specific stimuli shown and the participants' response decision rules by holding the stimuli constant. Thus, single alphabetic characters might be shown at the same rate as the stimuli presented as before, but periodically they would simultaneously change color, case, font, physical location, and value. Different groups of participants asked to respond whenever two

stimuli in succession were the same color or location (to engage the visuo-spatial scratchpad), or whenever the adjacent stimuli both contained a long "e" phoneme (to engage the phonological loop, or whenever they formed a 2-letter word (to focus on the central executive). The physical stimuli would remain the same as would the physical response. Any difficulties between the single tasks or between their effects on the writing process would then simply be the result of the instructions designed to engage working memory components differentially.

Clearly much remains to be discovered concerning visuo-spatial working memory in general and specifically in the role of visuo-spatial processes in writing. It is likely that developments in working memory and multiple resource theories will continue to influence the way visuo-spatial and verbal processes are investigated.

APPENDIX A
Experiment 1 stimuli

1	w d j k m
2	z t b p k
3	h q s c v
4	k p j f x n
5	f w y k p v
6	r w f g k r
7	w t f j n p k
8	q t p k h d s

9 z c b m k y r

10 d r f v y j n p

11 k l y n f t r g

12 x t v h k w d g

13 w d v y h j l m q

14 r p y j n b x c w

15 z r x f h k n p y

16 p k g v w

17 s r y v x

18 w g t h k

19 p y j n m

20 w d c v g

21 z r v h y

22 t g j v w d

23 w f t h v k

24 w d g y j k

25 p f b s z t

26 y j v z r n

27 k d r t h q

28 h t f v s w g

29 s r c g b k p

30 q z g l p y m

31 k g b t y n r

32 z t y v b k p

33 l h k v r d g

34 q d z b t n y

35 f r w x s c b h

36 y h j k l b f w

37 d z t c y b k n

38 d g j l k h f s

39 q t r w y p h k

40 z d x f c g v h b

41 z m y g c e r x w

42 d j f k g m x n c

43 p k n t b r c m s

44 q z w d x g c h b

45 g d f v y r n k m

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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